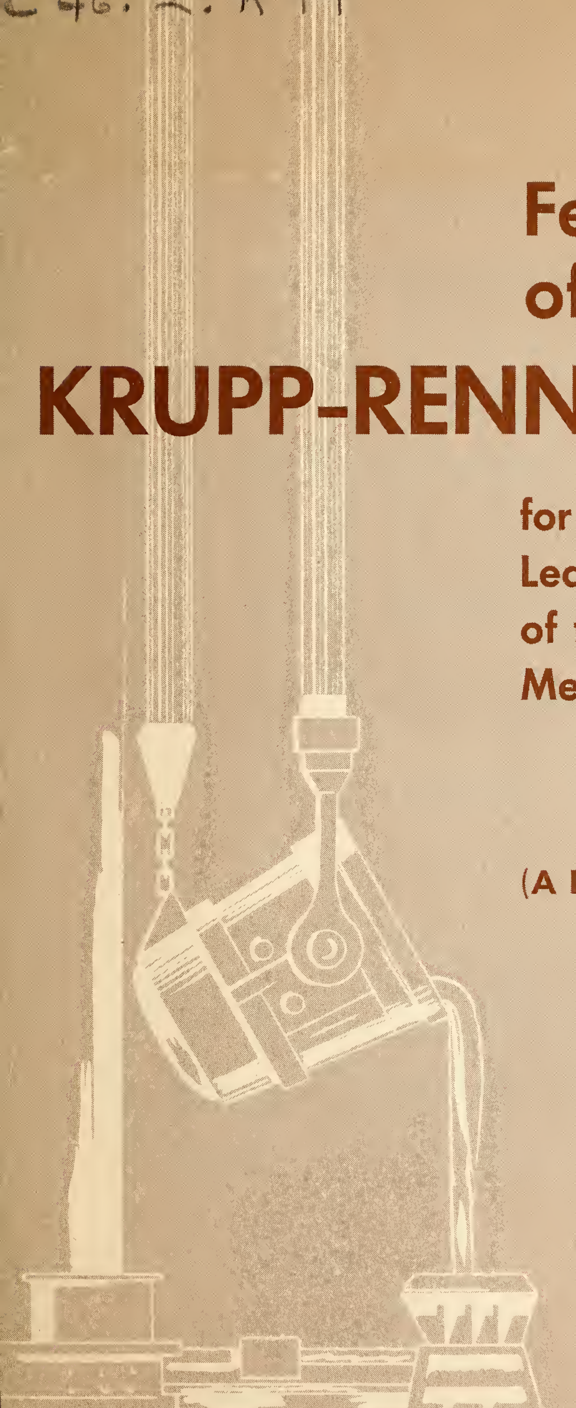
# Feasibility of the KRUPP-RENN PROCESS

## for Treating the Lean Iron Ores of the Mesabi Range



(A DIGEST)



U.S. DEPARTMENT OF COMMERCE / Area Redevelopment Administration

# Feasibility of the KRUPP-RENN PROCESS

## for Treating the Lean Iron Ores of the Mesabi Range

(A DIGEST)

U.S. DEPARTMENT OF COMMERCE
Luther H. Hodges, *Secretary*

AREA REDEVELOPMENT ADMINISTRATION
William L. Batt, Jr., *Administrator*

MAY 1964

For sale by the Superintendent of Documents, U.S. Government Printing Office
Washington, D.C., 20402 - Price 15 cents

## FOREWORD

This report is a condensation of a series of studies relating to the feasibility of adopting the Krupp Renn process for treating the non-magnetic lean iron ores of the Mesabi Range. The studies were undertaken at the request of the Itasca County (Minnesota) Area Redevelopment Agency with the cooperation of the Area Redevelopment Administration. They were prepared by the Southwestern Engineering Company, Los Angeles, California and Zontelli Brothers, Ironton, Minnesota. Copies of the complete report are available for reference at the Office of Planning and Research, Area Redevelopment Administration, Department of Commerce, Washington, D. C. 20230.

William L. Batt, Jr., Administrator
Area Redevelopment Administration

## CONTENTS

# INTRODUCTION

This feasibility study for a Krupp Renn plant for the Minnesota iron ranges was initiated at the request of the Itasca County, Minnesota Area Redevelopment Agency to the Area Redevelopment Administration. Itasca County, Minnesota, in which the middle and western end of the Mesabi iron range is located, has been declared a distressed area due largely to a slowdown in ore production. This slowdown of ore production has resulted from a combination of reduced steel production in the United States, and the use of high-grade ores from other countries such as Venezuela and Canada.

This project is concerned with the economic feasibility of reducing certain iron ores which have previously had little value since they had not proved amenable to beneficiation through traditional processes. The success, however, of the Krupp Renn process at Essen-Borbeck, Germany in reducing off-grade ores suggested its application to similar ore in the Minnesota area.

In order to determine the metallurgical and economic feasibility of locating and operating a Krupp Renn processing plant in northeastern Minnesota a three-phase study was established. Phases I and II were concerned with the metallurgical feasibility in laboratory and pilot plant operations. Phase III of the study involved an evaluation of the economic feasibility of the process.

Phase I involved testing three upgraded ore samples prepared by the University of Minnesota Mines Experiment Station in an electric furnace at the laboratories of Southwestern Engineering Company, Los Angeles. The Phase I laboratory tests indicated that Mesabi Cherty, Mesabi Painty, and Cuyuna Manganiferous ores would be amenable to processing in a Krupp Renn direct iron plant.

The second phase of the study involved work with Zontelli Brothers of Ironton, Minnesota, to investigate the metallurgical feasibility of applying the Krupp Renn process. Tests during this phase using the Krupp Renn process at Rheinhausen, Germany, proved the feasibility of operating the process on Zontelli type ore. These tests were conducted under the supervision of Southwestern Engineering Company as the United States licensee of Fried. Krupp Industriebau, Essen, Germany.

With the feasibility of the process determined, additional information was required preliminary to any move to full-scale production. Thus Phase III was initiated to: 1) Investigate and evaluate facility requirements with regard to plant size, material handling, and the like, 2) Advise prospective investors of the economic structure of the proposed facility, and 3) Facilitate market evaluation of the metallic iron product which will be produced.

## OBJECTIVES

The overall purpose of this report is to establish the economic feasibility of the Krupp Renn process as applied to available ores at three locations in the Minnesota iron ranges.

More specifically, the study is designed to achieve the following objectives:

- Investigation of the available reserves of usable ores.
- Establishment of the cost of raw materials for a full-scale plant including the approximate value conditioned upon its utilization in a Krupp Renn facility.
- Study of three suitable plant locations in Minnesota.
- Investigation of the area transportation facilities, including:

  Determination of the cost of moving raw materials to plant location.

  Estimate of the cost of moving metallic product Luppen[1] to shipping points.
- Establishment of annual production for an economic plant.
- Determination of cost per gross ton of final product.
- Incorporation into the final report of such necessary information as:

  Flow sheets.

  General arrangement drawings.

  Equipment list necessary to establish reliable capital and operating cost.

Other more detailed requirements of this study are included in the April 13, 1962 proposal of SWECO and Amendment No. 1 dated February 1, 1963, and Amendment No. 2 dated August 9, 1963. All the specific objectives and detailed requirements referred to previously have been accomplished and are included in the report.

---

[1] "Luppen" is the German term for blooms or lumps of iron obtained from the Catalan forge or from the puddling furnace.

## APPROACH

Upon receipt of the letter of intent from the Area Redevelopment Administration, Southwestern Engineering Company immediately initiated an investigation of ore sources and possible sites for a Krupp Renn facility. To accomplish this an engineering office was opened in Bovey, Minnesota, and staffed with Southwestern engineers.

Throughout the study, close liaison was maintained with Fried. Krupp consultants, in Germany.

Two consultants from Krupp directed engineering of the plant from October 17 to December 15, 1962. At this time design criteria and engineering layout were established, based, not only on theory, but also on practical knowledge developed from Krupp's experience in building similar facilities in Germany. Because the climate conditions of Krupp's plant at Frankenstein, Silesia, Germany are similar to those of the Lake Superior area, Krupp advised that the kilns be placed under cover to keep the feed materials from freezing in the day bin storage.

The Southwestern Engineering Company staff at Bovey was supplemented with engineers of the Abe Matthews Engineering Company of Hibbing, Minnesota. Providing as many as 10 engineers at one point in the study, Matthews Engineering prepared 75 preliminary drawings of the process and equipment. These drawings provided the basis for the development of detailed equipment lists and the preparation of finished drawings.

The engineering information for a three-kiln plant was completed by December 15 and remaining engineering work was transferred to Southwestern's Los Angeles office. The Bovey office was maintained until February 28, 1963 in order to obtain complete information with regard to equipment specifications and prices.

Early in 1963 it was determined that an economic evaluation of a six-kiln plant should be conducted and as a result a first extension was granted. The additional engineering, development of specifications, gathering of equipment cost information and tabulation of data was handled from Los Angeles.

In August 1963 a second extension was granted in order that a more comprehensive study of reserves could be conducted. In addition, since the Minnesota Legislature had passed additional semi-taconite laws, it also became necessary to obtain opinions as to how these new laws affected the negotiation of state ore leases as well as their tax impact on the project.

A summary of findings has been added to the report in order to allow the reader to evaluate the more important findings of this project.

## PLANT AND SITE INVESTIGATION

### The Krupp-Renn Process

The Krupp Renn process was developed in Magdeburg and Borbeck, Germany between 1931 and 1939 for the treatment of ores not economically adaptable to blast furnace use. This process is carried out in a rotary kiln and produces low carbon, high iron, metallic nodules known as "Luppen."

One of the major advantages of the Krupp Renn process is the variety and size of ore, flux, and reductant that can be used. At the time of development of the process, the chief aim was to find a method for using low-iron content siliceous ores which, due to their physical structure and chemical characteristics, could not be beneficiated economically by existing procedures. However, when industrial application was made of the process in both Watenstedt and recently Essen-Borbeck, the Krupp Renn process showed considerably better economics when using ores with approximately 50 per cent iron and high silica content.

The process consists of three main divisions; raw material preparation, kiln reduction, and slag-metal separation.

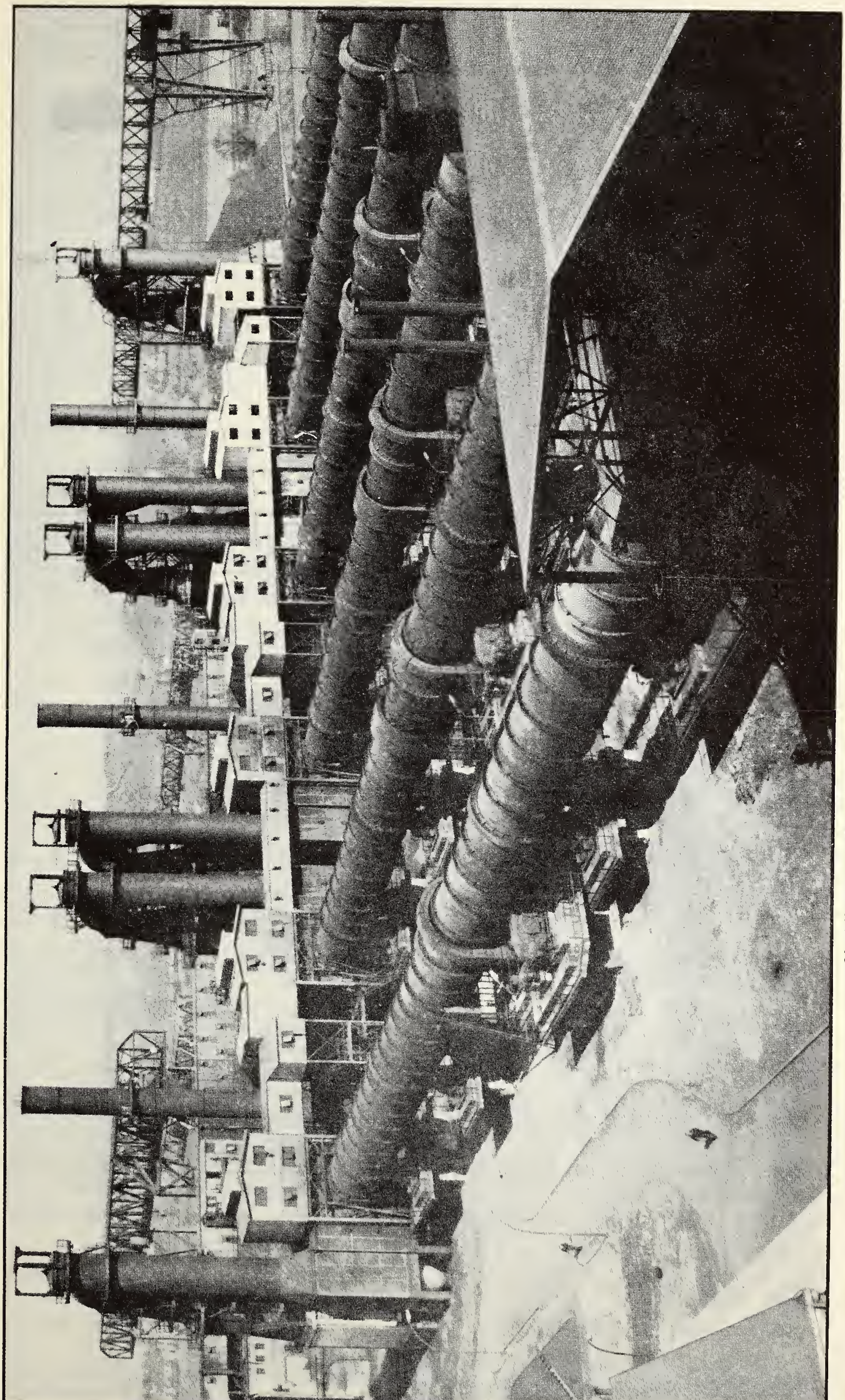
The raw materials used consist of the following:

*Ore.*—The ores that have been treated economically contain between 35 per cent and 51 per cent Fe and may have a silica content up to 30 per cent. A higher silica content can be handled if $AL_2O_3$ and CaO are present in sufficient amounts. The limitation on the silica content is the economics of maintaining the desired ratio of $SiO_2$ to CaO. If excessive amounts of slagging flux must be calcined in the kilns, the heat required in the feed end greatly increases the demand for reductant and also raises the temperature above that required for reduction.

*Reductant.*—The reducing agent can be any solid carbonaceous material of low volatile content and slow reactivity such as anthracite fines, coke breeze, or low-temperature char, sized to below 8 mesh. Tests conducted in Germany show that char produced from North Dakota lignite is equally reactive and can be used in place of anthracite fines. It is desirable to have the reductant as low in sulphur content as possible, as only 70 percent of the sulphur is removed in the process without additional fluxes for this purpose.

*Flux.*—In an application for the ores of the Iron Range, off-grade metallurgical limestone can be used, the amount being dependent upon the silica and alumina present in the ore. A desirable slag contains approximately 62 per cent silica, 14 per cent alumina, and 24 per cent bases.

*Heating Fuel.*—The heating fuel, which is used intermittently to hold a uniform temperature at the discharge end, would be of such a



Six-kiln Krupp-Renn plant near Essen-Borbeck, Germany

nature as to provide a long, radiant flame similar to that used in open-hearth operation. Coal fines with 20 per cent volatiles or fuel oil have been used successfully. Also, it is believed natural gas can be used if it is partially carburized with fuel oil.

*Kiln Reduction Process.*—In the Krupp Renn process, the ore is removed from the ore yard after being blended to obtain a uniform analysis and, along with the reductant and limestone, is transferred to separate storage bins located at the feed end of the kilns. From the feed bins, the raw materials are fed at pre-determined proportions by constant weight feeders and delivered to the rotary kilns. The size of the kiln is dependent upon the quantity of production required. In Krupp Renn kilns there are three generally recognized zones; the first third is the preheating or drying zone, the second third the reduction zone, and the final third the Luppen zone. In the first zone, the mixture of ore, fuel, and limestone is heated and dried by the waste gases, produced from the heating flame and the burning of the reductant. After adequate preheating of the charge, the iron oxide is converted in the second ore reduction zone into particles of sponge iron which remain finely dispersed in the still unfused gangue. The last, or Luppen zone, terminates in a firebrick ring which causes the charge to build up, resulting in a retention time in this zone of several hours. As the reduction is now practically complete, only a small amount of carbon monoxide is released and the air and oxidizing heating gases, introduced from the discharge end of the kiln, impinge upon the surface of the charge. This causes a vigorous re-oxidation of the sponge iron exposed at the surface and effects a sudden increase in temperature and local formation of a ferrous-oxide-bearing slag. This slag segregates from the sponge iron, the metallic skeleton of the latter at the same time welding together to form a solid Luppen. The rate of slag segregation and Luppen formation is considerably increased by the tumbling action of the charge in the revolving kiln. The oxidized surface layer is worked back into the middle of the charge where the previously oxidized iron is again reduced by the excess carbon present, and a metallic iron of low carbon content is produced.

*Slag Separation.*—The kiln discharge of pasty slag enveloping the Luppen is delivered by gravity to a barrel-type cooler where it is quenched to form a glassy slag containing the iron nodules. After air cooling and drying, the slag is removed by grinding, screening, and magnetic separation of the Luppen. The slag is delivered to the slag disposal area, leaving the Luppen, high-iron bearing nodules.

The word "Renn" is derived from "Rennfeuer" (bloomery), an antique iron-making process in use before the blast furnace became known. The metallurgical reactions taking place in the "Rennfeuer" (the Catalan forge is one particular type) were similar to those in the modern Renn process. "Rennen" (to smelt) is the transitive form of the old German word "rinnen" and thus means "to make run, flow, trickle, ooze."

**Plant Design**

- General Information
- Design Criteria—6-Kiln Plant
- Mechanical Equipment Costs
- Summary of Capital Costs

*General Information.*—Southwestern Engineering Company with the aid of the Krupp Renn engineers laid out the plant design for both the three- and six-kiln plants. Essentially the same land requirement and supporting facilities were needed for either the three- or the six-kiln plants. Thus, plot plans are available for both the three-kiln plant, providing for future expansion, and the six-kiln plant.

Due to the severe freezing conditions in northern Minnesota during the coldest three months of winter, it was decided to provide covered storage for the ore. Since the ore charge to the kiln has a 10 per cent moisture content, freezing could occur in the charge during the coldest winter months. Therefore, it was determined to place the day bins for storage of the charge between the line of kilns and provide cover in order that the heat dissipated from the kiln shells be sufficient to keep the ore and other materials from freezing.

Abe Matthews Engineering Company of Hibbing, Minnesota assisted Southwestern Engineering Company in the layout, preliminary sizing of equipment and the design of structures.

*Engineering Design Criteria.*—This section has been prepared largely by the consulting engineers of Fried. Krupp, and has been included essentially as presented by them. The units of weight in this section are, therefore, those customarily used by European engineers. No attempt has been made to reduce these to U.S. common usage. However, this was taken into account in our design and our other calculations with the following equivalents:

| | | |
|---|---|---|
| Metric tons approximately equal to long tons | = | 2,240 lbs. |
| Short tons | = | 2,000 lbs. |

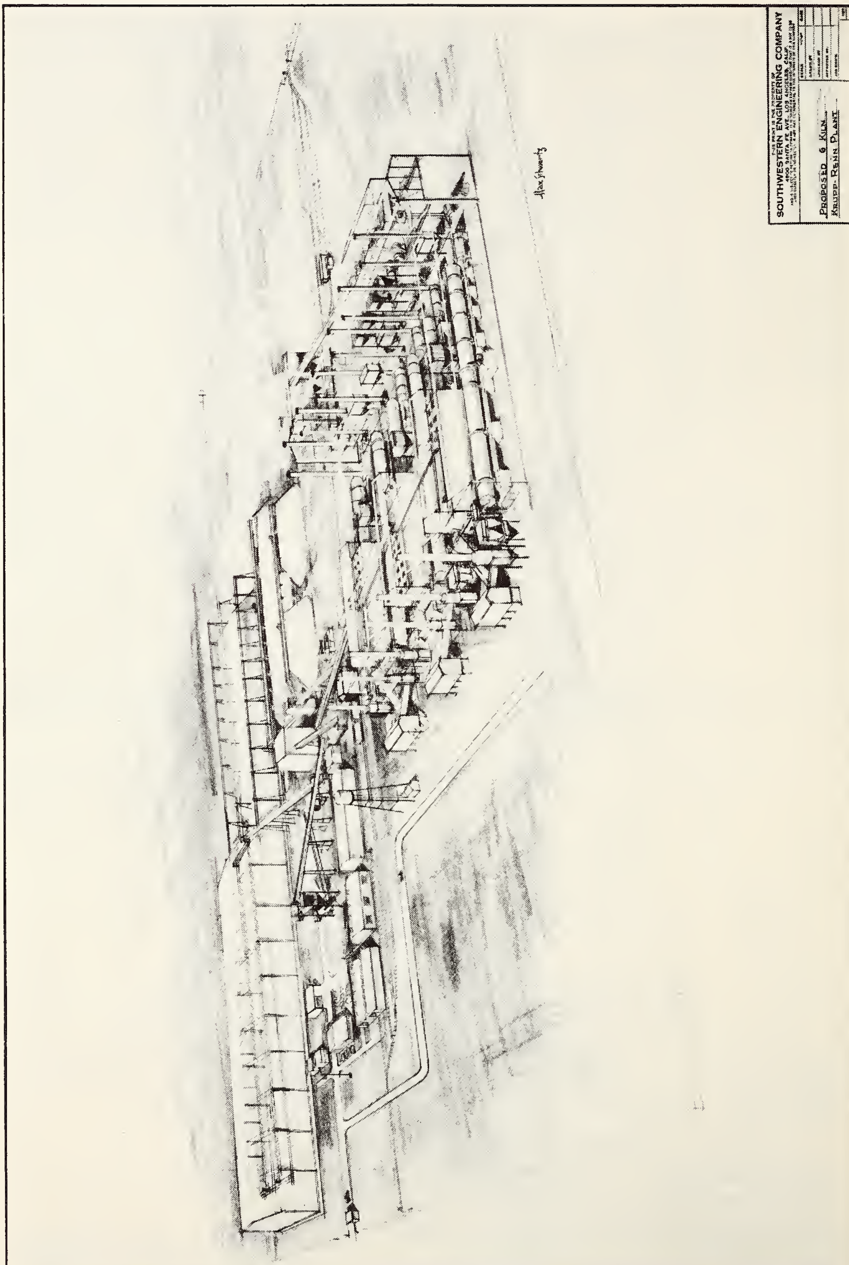
Engineering design criteria for the six-kiln plant has been detailed in this section in terms of:

- Raw Materials
  - Iron Ore
  - Limestone
  - Anthracite Coal
  - Bituminous Coal
- Kiln Throughput
- Slag Alley
- Magnetic Separation
- Product Shipping and Storage
- Magnetic Concentrates
- Dust Collection
- Heating Coal Pulverizing Systems

*Raw Materials.*—The basic throughput for each kiln is 800 metric tons per day. This tonnage covers ore and limestone. It does not cover the amounts of reductant coal or heating fuel which are changed to hot gases during the process. In the six-kiln plant, the basic throughput is 4,800 metric tons per day. All of the design criteria are based on this approximate quantity:

- Ore—1,460,000 long tons per year
- Limestone—142,000 short tons per year
- Reductant coal—474,000 short tons per year
- Kiln heat fuel (Bituminous coal)—98,000 short tons per year

*Iron Ore.*—Material handling is accomplished by the use of three sizes of conveyors, 24 inch, 30 inch, and 36 inch. The selection of these sizes is predicated to a maximum size required, 36 inch and the minimum size, 24 inch. Although several conveyors will operate at a




Proposed layout of a Krupp-Renn plant prepared for the ARA project.

less than maximum efficiency, this will enable stores to carry a minimum of spare parts and belting for future repair and replacement. In the event of future expansion, all conveyors are sized to handle an additional load through working more turns per week.

Ore feed requirements are approximately 1,460,000 long tons per year. Because of freezing conditions in northern Minnesota during the winter months, it is anticipated that ore delivery will be over an eight-month period. Ore will be delivered to the plant site by rail in cars having a capacity of 70 LT. Ore can be delivered by truck if required. Ore unloading will require fifteen 8-hour shifts per week, Monday through Friday.

A railroad trackage having a capacity of 180 standard railroad cars will be provided so that all raw materials and finished product cars can be shuttled and stored.

Ore will be dumped into a hopper at a rate of one car per 10 minutes and thence to a primary crusher at a rate of 385 tons per hour. Eighteen inch maximum ore will be crushed to minus 6 inch.

After secondary crushing to minus 3 inch, the ore will be diverted to either an ore dryer or to summer storage area. The ore dryer will have a capacity of 175 LT per hour. The ore for winter use will be dried to 5 per cent moisture, and transferred by conveyor to the covered ore storage building.

The balance of the ore will be transferred by conveyor and placed by elevated stackers, as above, to the summer storage area, which has a capacity of 96,000 LT. Ore will be stockpiled in such a manner as to lay it down in approximately 18 inch layers to insure a uniform blend feed to the kilns. The ore is reclaimed from either stockpile by front end loaders to loading ports located above a concrete tunnel. The ore is then conveyed by belt conveyors to the tertiary section of the crushing plant.

The ore must be crushed to minus ¾ inch. After tertiary crushing, the ore will be conveyed to elevated concrete day bins within the kiln building. Each kiln will have sufficient day bins to provide a two and a half day supply of feed.

*Limestone.*—Flux requirement of limestone is 430 ST per day. Limestone will be delivered by suppliers to the job site in railroad cars and will be dumped in hoppers for conveying to the limestone storage stockpile. This stockpile will have a capacity of 30 days' operation. Suppliers can provide continuous delivery, crushed to specifications. Limestone will be reclaimed from storage by gravity flow to a tunnel, thence conveyed to day bins located within the kiln building. The day bins will have a capacity of two and a half days' supply. This section of the plant will operate on ten 8-hour shifts per week, Monday through Friday.

*Anthracite.*—Total requirement of reductant coal per day is 1,430 short tons. Anthracite will be delivered by suppliers to the job site in railroad cars and will be dumped in hoppers for conveying to the anthracite storage stockpile. This stockpile will have a capacity of 30 days' operation. Suppliers can provide continuous delivery crushed to specifications. Anthracite will be reclaimed from storage in the same manner as limestone, and conveyed to the day bins located within the kiln building. The day bins will have a capacity of two and a half days'

supply. This section of the plant will also operate on ten 8-hour shifts per week, Monday through Friday.

*Bituminous Coal.*—Total requirement of heating fuel per day is 296 short tons. Bituminous coal will be delivered by suppliers to the job site in railroad cars and will be dumped in hoppers for conveying to the bituminous coal storage stockpile. This stockpile will have a capacity of 30 days' operation. Suppliers can provide continuous delivery crushed to specifications. Bituminous coal will be reclaimed from storage in the same manner as limestone, and conveyed to the day bins located within the kiln building. The day bins will have a capacity of two and a half days' supply. This section of the plant will operate on ten 8-hour shifts per week, Monday through Friday.

*Kiln Throughput.*—One of the most critical functions of our material handling in the plant is the proportional feed of ore, reductant, and flux. Through a system of precise weigh feeders located underneath the day bins, the ore, reductant, and flux will be placed on a conveyor and transferred to the kiln feed pipe. The plant shall be designed for the following average kiln throughput:

| *Feed* | *Size* | *Quantity* |
|---|---|---|
| Ore | 0 to ½″ | 30.1 Long Tons per Hour |
| Limestone | 1/16 to 3/16″ | 2.7 " " " " |
| Anthracite | 0 to ⅛″ | 8.25 " " " " |
| Dust | --- | 6.5 " " " " |
| Magnetic Concentrates | 0 to 3/16″ | 3.25 " " " " |

Individual items may be designed for 10 per cent more throughput than shown above. The kiln discharges molten slag and Luppen at a rate of 27 LTH into barrel coolers for first stage cooling.

*Slag Alley.*—The slag discharged from the barrel coolers is moved by the bucket cranes and deposited in the slag alley for further cooling prior to being fed to the separation circuit. This operation is continuous, 24 hours a day and 7 days a week.

The slag alley cranes discharge to the bins feeding the magnetic separation circuits. Since the separation circuits will operate fifteen 8-hour shifts per week, the cranes must have the capacity to handle the separation feed plus the barrel cooler discharge during 120 hours each week. The remaining time, the cranes tend the barrel coolers only.

*Magnetic Separation.*—Four magnetic separation circuits operating fifteen 8-hour shifts per week will handle the throughput from 6 kilns.

A slotted tube mill, seven magnetic separators and one bucket elevator are needed in each circuit. The tube mill capacity can be about 75 per cent of 57 LTH or 43 LTH. The balance is removed by screening slag and Luppen prior to feeding the tube mills.

The hourly discharge from the magnetic separation is:

| | *One Circuit* | *Four Circuits* |
|---|---|---|
| Luppen | 28.0 LTH | 112.0 LTH |
| Middlings | 8.5 LTH | 34.0 LTH |
| Slag | 20.5 LTH | 82.0 LTH |
| | 57.0 LTH | 228.0 LTH |

*Product Shipping and Storage.*—Approximately 2,700 LT of Luppen is discharged from the separation circuits each working day of three 8-hour shifts. This is conveyed to the railroad loading bins, which can store two days' production, for shipment or, during the winter to the covered storage area where additional Luppen can be stored as the winter's supply of ore is used. When the lake opens in the spring all the stored Luppen will be shipped to the Duluth docks.

*Magnetic Concentrates.*—The feed for each kiln includes 3.5 LTH of recycled concentrates. Each separation circuit discharges 8.5 LTH. The concentrates are conveyed from the separation building to a surge bin and thence to the day bin.

*Dust Collection.*—Dust collection must satisfactorily comply with State, County, City and other governmental requirements, and also with the latest industry standards. There are four areas where dust collection and control are required. They are: Crusher building, dryer area, kilns, and magnetic separation area.

### CRUSHER BUILDING

Collects iron ore dust from the crushers, screens, and conveyor belts for the several crushing stages. The design air flow for this system is 18,600 CFM. The dust is collected and fed back to the day bins feed conveyor.

### DRYER

Each vendor is required to furnish adequate dust collection for his unit in the dryer cost estimate. The dust is collected and fed back to the conveyor taking the discharge from the dryer.

### KILN

The dust collection system for each kiln must handle 136,000 CFM of hot gases (890°F.). The maximum dust loading is 130 grams per cubic meter. The dust is collected and cooled through cyclones and then conveyed to a dust storage bin. This dust is then added to the kiln charge.

### MAGNETIC SEPARATION

The dust collection system for each magnetic separation circuit shall be as specified by Krupp. Dust is collected from the vibrating screens, tube mill and conveyors. It is fed to a dust bin and fed across a magnetic separator to recover the Luppen.

*Heating Coal Pulverizing Systems.*—Each kiln requires 50 tons/24 hours or 2.08 tons per hour of heating coal. This coal must be pulverized and blown into the discharge end of the kilns.

Each kiln shall be equipped with an individual direct fired system. Drying air for the pulverizer shall be by oil fired dryers, one for each system.

## Mechanical Equipment Costs

The six-kiln plant has a total equipment cost of $16,700,000 repre-

sented by the following four cost categories and is listed by the percentage cost of equipment:

- Kiln operation 73%
- Material handling 12%
- Magnetic separation 10%
- Auxiliary Equipment 5%

Although detailed equipment lists are available for the six-kiln plant (and three-kiln plant), the most important equipment amounting to the majority of the costs in each category, is summarized below:

KILN OPERATION

| | |
|---|---|
| Kilns with linings | $10,100,000 |
| Kiln firing | 260,000 |
| Kiln dust collections | 820,000 |
| Barrel Coolers | 450,000 |
| | $11,630,000 |

These four items represent 93 per cent of the costs of this category.

MATERIAL HANDLING

| | |
|---|---|
| Conveyors | $1,300,000 |
| Crushers | 310,000 |
| | $1,610,000 |

These two items represent 80 per cent of the costs of this category.

MAGNETIC SEPARATION

| | |
|---|---|
| Slotted Ball Mills | $ 750,000 |
| Bucket Elevators and Vibrating Screens | 45,000 |
| Magnetic Separators | 210,000 |
| Dust Collection | 130,000 |
| Conveyors | 80,000 |
| | $1,215,000 |

These five items represent 75 per cent of the costs of this category.

AUXILIARY EQUIPMENT

| | |
|---|---|
| Locomotives | $200,000 |
| Maintenance Equipment | 185,000 |
| Boilers | 50,000 |
| Compressors | 10,000 |
| | $445,000 |

These four items account for 70 per cent of the costs of this category.

*Summary of Capital.*—This section summarizes the costs of the plant—direct and indirect as well as administrative for the six-kiln and

three-kiln plants. Costs are identified as to whether they are material, labor or sub-contract.

The principal increases in costs of a six-kiln plant over a three-kiln plant exist in kiln operation $13,551,937 − 7,093,800 = 6,458,137; and related concrete construction 2,495,925 — 1,800,000 = 695,925; steel construction 3,674,326 — 2,846,000 = 828,326; electrical work 2,309,679 − 1,593,953 = 715,726 and magnetic separation 1,845,-647 − 1,340,905 = 504,742. Thus these five cost areas account for $9,202,856 or 77 per cent of the difference in cost between the six- and three-kiln plants.

## CAPITAL COST FOR SIX-KILN PLANT

| *Direct Costs* | *Material* | *Labor* | *Subcontracts* | *Total* |
|---|---|---|---|---|
| Land Acquisition | $ 13,200 | $ ------ | $ ------ | $ 13,200 |
| Site Preparation | ------ | ------ | 44,800 | 44,800 |
| Earthwork | ------ | ------ | 82,000 | 82,000 |
| Concrete Construction | ------ | ------ | 2,495,925 | 2,495,925 |
| Steel Construction | ------ | ------ | 3,674,326 | 3,674,326 |
| Roads, Fencing, Railroads | ------ | ------ | 271,400 | 271,400 |
| Buildings (Service) | ------ | ------ | 252,000 | 252,000 |
| Electrical | 922,629 | ------ | 1,387,050 | 2,309,679 |
| Piping | ------ | ------ | 210,000 | 210,000 |
| Mechanical Equipment: | | | | |
| Material Handling | 2,018,357 | 180,000 | 58,285 | 2,256,642 |
| Kiln Operation | 11,448,449 | 1,190,000 | 913,488 | 13,551,937 |
| Magnetic Separation | 1,655,657 | 190,000 | ------ | 1,845,657 |
| Mobile & Shop | 658,854 | 20,000 | ------ | 678,854 |
| Instrumentation | 110,000 | ------ | 50,000 | 160,000 |
| Insulation | ------ | ------ | 24,000 | 24,000 |
| Painting | ------ | ------ | 61,264 | 61,264 |
| Heating & Ventilation | ------ | ------ | 149,550 | 149,550 |
| Total Direct Costs | $16,827,146 | $1,580,000 | $9,674,088 | $28,081,234 |
| *Field Indirect Costs* | | | | |
| Small Tools & Supplies | $ 65,000 | $ ------ | $ ------ | $ 65,000 |
| Construction Equipment | ------ | ------ | 180,000 | 180,000 |
| Temporary Construction | 40,000 | 30,000 | ------ | 70,000 |
| Tests and Inspection | ------ | ------ | 35,000 | 35,000 |
| Field Supv. & F. O. Pers. | ------ | 310,000 | ------ | 310,000 |
| Field Office Expense | 48,000 | ------ | ------ | 48,000 |
| P/R Taxes, Comp. Pl. & Pd. | 45,320 | ------ | ------ | 45,320 |
| All Risk Insurance | 43,500 | ------ | ------ | 43,500 |
| Subsistence & Travel | 230,000 | ------ | ------ | 230,000 |
| Total Indirect Field Costs | $ 471,820 | $ 340,000 | $ 215,000 | $ 1,026,820 |
| Total Costs, A & B | $17,298,966 | $1,920,000 | $9,889,088 | $29,108,054 |
| *Home Office Costs* | | | | |
| Enginering | $ 218,310 | $1,237,090 | $ ------ | $ 1,455,400 |
| Purchasing | 21,820 | 123,670 | ------ | 145,500 |
| Overhead 85% | ------ | ------ | ------ | 1,443,462* |
| Krupp (Start-Up) | ------ | ------ | 60,000 | 60,000 |
| Contingency 5% | ------ | ------ | ------ | 1,455,400* |
| Krupp Fee | ------ | ------ | ------ | 620,000* |
| A.R.A. | ------ | ------ | ------ | 175,000* |
| Total Home Office Costs | $ 240,130 | $1,360,760 | $ 60,000 | $ 5,354,762 |
| Total All Costs, A. B. & C. | $17,539,096 | $3,280,760 | $9,949,088 | $34,462,816 |
| Fee | ------ | ------ | ------ | 3,446,282* |
| Project Total | ------ | ------ | ------ | $37,909,098 |

* These figures show total cost.

## CAPITAL COST FOR THREE-KILN PLANT

| *Direct Costs* | *Material* | *Labor* | *Subcontracts* | *Total* |
|---|---|---|---|---|
| Land Acquisition | $ 13,200 | $ ------ | $ ------ | $ 13,200 |
| Site Preparation | ------ | ------ | 44,800 | 44,800 |
| Earthwork | ------ | ------ | 82,000 | 82,000 |
| Concrete Construction | ------ | ------ | 1,800,000 | 1,800,000 |
| Steel Construction | ------ | ------ | 2,846,000 | 2,846,000 |
| Roads, Fencing, Railroads | ------ | ------ | 271,400 | 271,400 |
| Building (Service) | ------ | ------ | 252,000 | 252,000 |
| Electrical | 563,297 | ------ | 1,030,656 | 1,593,953 |
| Piping | ------ | ------ | 130,000 | 130,000 |
| Mechanical Equipment: | | | | |
| Material Handling | 1,751,268 | 165,000 | 58,285 | 1,974,553 |
| Kiln Operation | 5,882,661 | 600,000 | 611,139 | 7,093,800 |
| Magnetic Separation | 1,195,905 | 145,000 | ------ | 1,340,905 |
| Mobile & Shop | 658,854 | 20,000 | ------ | 678,854 |
| Instrumentation | 90,000 | ------ | 40,000 | 130,000 |
| Insulation | ------ | ------ | 14,000 | 14,000 |
| Painting | ------ | ------ | 40,000 | 40,000 |
| Heating & Ventilating | ------ | ------ | 125,000 | 125,000 |
| Total Direct Costs | $10,155,185 | $ 930,000 | $7,345,280 | $18,430,465 |
| *Field Indirect Costs* | | | | |
| Small Tools & Supplies | $ 60,000 | $ ------ | $ ------ | $ 60,000 |
| Construction Equipment | ------ | ------ | 140,000 | 140,000 |
| Temporary Construction | 35,000 | 250,000 | ------ | 60,000 |
| Tests & Inspection | ------ | ------ | 30,000 | 30,000 |
| Field Supv. & F.O. Pers. | ------ | 230,000 | ------ | 230,000 |
| Field Office Expense | 36,000 | ------ | ------ | 36,000 |
| P/R Taxes, Comp. Pl. & Pd. | 41,200 | ------ | ------ | 41,200 |
| All Risk Insurance | 38,000 | ------ | ------ | 38,000 |
| Subsistence and Travel | 180,000 | ------ | ------ | 180,000 |
| Total Field Indirect Costs | $ 390,200 | $ 255,000 | $ 170,000 | $ 815,200 |
| Total Costs, A & B | $10,545,385 | $1,185,000 | $7,515,280 | $19,245,665 |
| *Home Office Costs* | | | | |
| Engineering | $ 196,560 | $1,113,300 | $ ------ | $ 1,309,860 |
| Purchasing | 19,680 | 111,300 | ------ | 130,980 |
| Overhead 85% | ------ | ------ | ------ | 1,236,410* |
| Krupp Start-up | ------ | ------ | 60,000 | 60,000 |
| Contingency 5% | ------ | ------ | ------ | 962,783* |
| Krupp Fee | ------ | ------ | ------ | 440,000* |
| A.R.A. | ------ | ------ | ------ | 175,000* |
| Total Home Office Costs | $ 216,240 | $1,224,600 | $ 60,000 | $ 4,315,033 |
| Total All Costs, A. B. & C. | $10,761,625 | $2,409,600 | $7,575,280 | $23,560,698 |
| Fee | ------ | ------ | ------ | 2,357,070* |
| Project Total | ------ | ------ | ------ | $25,917,768 |

* These figures at total cost.

### Site Investigation

Upon investigation of the three range areas and the Lake Superior-Duluth area, three plant sites are submitted as alternatives for the location of a Krupp Renn facility. They are located generally in the:

- Lake Superior-Duluth area
- Hibbing-Kelly Lake area of the Mesabi Range
- The Trommald area of the Cuyuna Range

*Lake Superior-Duluth Area.*—The Lake Superior-Duluth plant site and information thereto is covered in detail in the report of the Duluth

Industrial Bureau. Two alternative locations are available in the Lake Superior-Duluth area. The primary advantage of this general location would be the ease and economy with which finished products might be transported from plant site to vessels, and anthracite No. 4 Buckwheat fines and limestone from vessel to plant site. This is true, however, only if plant site and dock are contiguous. Neither site provides this advantage and from all information, none could be made available.

According to the Great Northern Railway and Northern Pacific Railway rate information, the freight rate for iron ore if for processing in the Duluth area would be $1.47 per long ton plus a minimum through charge of 75¢ per long ton for transporting the Luppen to the dock and loading. In addition, freight must be added to ship the anthracite and limestone to the plant sites available at Adolph (Site 1) and Riverside (Site 2). It is estimated that a suitable plant site could be acquired for approximaely $13,200.

*Hibbing-Kelly Lake Area.*—The Hibbing-Kelly area of the Mesabi Range provides a second alternative. The area is flat and suitable for plant site and storage as necessary. It is also served directly by the Great Northern Railway and is near various ore reserves. Based on the information of the real estate appraiser, it is estimated that a suitable plant site could be acquired for between $15,000 and $20,000.

It is anticipated that the shipment of Luppen from Kelly Lake to Duluth would be at the same rate as all iron ore from all points on the Range to Duluth, or $1.47 per long ton including up to 10 days storage at dock site and loading aboard vessels. (Storage charges after 10 days are assessed at the rate of ½¢ per ton per day or any fraction thereof.) It does not appear that any concessions as to freight rates would be granted over iron ore or taconite despite the fact that Luppen is not susceptible to damage, has excellent handling characteristics and has a density approximately three times that of direct shipping ore.

*The Trommald Area.*—The Trommald area of the Cuyuna Range, is the third alternative site location. This area is served by the Northern Pacific Railroad lines and is adjacent to ore reserves. A railway right of way exists into the village of Manganese, which is contiguous to this property and would lend itself to a spur-line service to the plant site.

Upon checking the status of title to this property, it appears that the Southeast Quarter has been forfeited for unpaid taxes, and the Southwest Quarter is presently held by Herman Hunter, Jr., with the mineral rights reserved in Werhauser. Without conducting extensive drilling, it is the consensus of those in the area that the property is not valuable for mineral rights. Consequently, the surface use of the property would not be hindered. It is anticipated that a price of approximately $15,000 would purchase the South One-half of Section 29, Township 47, Range 29.

The freight rate for anthracite #4 Buckwheat fine and Limestone via Northern Pacific, as presently established to Trommald, Minnesota, is $2.59½ per ton for anthracite and $1.50 per ton for limestone.

Again, it is anticipated as with the Kelly Lake, Mesabi Range site that the freight rate on Luppen from Trommald to Duluth for shipment by vessel to other points will not be less than $1.47 per ton including 10 days storage and loading aboard vessels. Definite rates must be established by the eventual operator in a letter to the railway.

## SUMMARY OF FINDINGS

### Minnesota's Iron Ore Situation

The iron ores of Minnesota's Mesabi, Cuyuna and Vermillion iron ranges were, for many years, a product very much in demand by the steel industry in the lower lakes area. During recent years, the requirements of the furnace operators for high iron, low silica ores, plus increased competition from the ores of the Labrador-Trough area of Canada and from South America have cut deeply into the annual shipments from this area. Yet there exist large tonnages of lean ore reserves carrying from 35 to 50 per cent iron. Much of this material lies in lean-ore dumps, gravity-reject piles and finetailings ponds, while additional large tonnages lie wholly or partially stripped in existing open-pit mines. Huge expenditures are being made to exploit the iron ore deposits of Canada and other foreign countries which provide ore in direct competition to the ores from Minnesota. Many of these ores are either very high grade in their natural state or can be beneficiated to produce a very high quality product assaying from 64 to 68 per cent iron. These foreign projects, however, require millions of dollars of investment for such items as railroads, electric power and town site facilities, in addition to the investment required for mining equipment, processing plants and harbor facilities.

Minnesota presently has, in addition to the large reserves of low-grade iron ore, excellent facilities in the form of railroads, electric power, towns and harbor facilities as well as a highly qualified, well trained labor force. Despite these advantages, the production of ores from the iron ranges of Minnesota has steadily decreased with unemployment and economic conditions worsening each successive year due to competition of foreign ores.

Members of top management of nearly every major steel company have carefully considered the possible application of direct reduction processes to the available lower grade ores. Aware of the significant changes in iron production as a result of sinter and pellet availability, they are now looking beyond these products to the eventual usage of an even more highly beneficiated burden; the metallic pellet.

In many instances, the lack of information concerning direct reduction processes has hampered adequate consideration of their specific application. It is now recognized that several processes exist—and additional processes will emerge—which are capable of producing metallic pellets from raw materials currently available in abundance on the Minnesota iron ranges.

## Ore Availability

Investigation indicates that sufficient ore reserves are available in Minnesota to meet the requirement of a plant designed to produce at least 600,000 tons of pellets annually with an iron content in excess of 92 per cent. These ores are now considered worthless because of their high-silica content (12 to 30 per cent), they cannot be economically beneficiated by any process other than Krupp Renn.

At least three sources were found of this semi-taconite ore:

• Zontelli Brothers, Semi-taconite, Cuyuna Range, Crosby-Ironton, Minnesota. (Claim to have sufficient ore available but will not state exact amount of reserves.)

| *Ore Analysis* | *Dry* | *Natural* |
|---|---|---|
| Fe | 50.0% | 45.45% |
| $SiO_2$ | 17.0% | 15.45% |
| $Al_2O_3$ | 3.5% | 3.18% |
| Moisture | | 10.00% |

• Northern Pacific, Semi-taconite, Central Mesabi Range, Bovey, Minnesota (10 million tons available).

| Ore Analysis | A* | B* | 25% B 75% A + | 10% Mois. AB* + |
|---|---|---|---|---|
| Fe | 50.0% | 44.0% | 48.50% | 44.1% |
| $SiO_2$ | 16.0% | 29.0% | 19.25% | 17.5% |
| $Al_2O_3$ | 3.5% | 1.0% | 2.88% | 2.6% |
| Moisture | | | | 10.0% |

• Oliver Iron Mining Division Paint Rock—Hibbing area (18.5 million tons available).

| *Ore Analysis* | *Natural* | *10% Moisture* |
|---|---|---|
| Fe | 39.06% | 42.7% |
| $SiO_2$ | 14.17% | 15.1% |
| $Al_2O_3$ | 5.28% | 5.7% |
| Moisture | 16.31% | 10.0% |

All of the ores are suitable for reduction by the Krupp Renn process.

## Feasibility of Six-kiln vs. Three-kiln Plant

The six-kiln plant was found to have a substantial economic and socio-economic advantage over a three-kiln plant because of the following factors:

• Three-kiln is not as profitable as six-kiln—e.g., Zontelli ore processed at Cuyuna shows a return on equity of 2.7 per cent for three-kiln at $35 per ton price vs. 17.3 per cent for the six-kiln at the same price.[1]

• Profitability of six-kiln increases much more than capital require-

* Two ore deposits are available at Northern Pacific, shown as A and B, with three times as much A available as B, thus they were combined in these proportions for ore evaluation.

[1] Represents a return after taxes on $10,000,000 equity.

ment since auxiliary equipment such as material handling for three-kiln is comparable to that for six-kiln.

- Six-kiln plant employs 375 vs. 284 for three-kiln. This will provide greater economic stimulus for the area.

Both the six-kiln and the three-kiln plants were designed and estimated as completely integrated facilities. This was done in order that all costs would be available for construction of a completely new plant. However, if the Krupp Renn process were added to an existing facility, the cost of office, shops, and so forth would be reduced according to the nature and capacity of existing facilities. Thus the economics of the plant would undoubtedly look even better from a capital and operating cost standpoint if it were added to an existing plant.

### Economics of Six-kiln Plant

The economic feasibility of the six-kiln Krupp Renn plant was determined for Zontelli Brothers ore, Northern Pacific ore, and Oliver ore in terms of a plant location at Lake Head, Hibbing and Cuyuna. Since Zontelli ore at Hibbing, Northern Pacific at Cuyuna and Oliver at Cuyuna are obviously uneconomic,[2] these variations were not calculated.

Thus cost of data was developed for six possibilities:

- Zontelli at Lake Head
- Zontelli at Cuyuna
- Northern Pacific at Lake Head
- Northern Pacific at Hibbing
- Oliver at Lake Head
- Oliver at Hibbing

The costs of these six possibilities are summarized in Table 1, which indicates in dollars per ton, by ore source and plant location, raw material costs, direct labor costs, operating costs, depreciation, indirect costs, freight on board ship, and total costs. Freight costs to Lake Head on board ship are presented in terms of freight costs comparable to the current cost of shipping ore.[3]

All possibilities have been presented on this single table (Table 1) in order to make comparison of total costs and sub-costs simpler. Although the relationship between various plant sites is apparent, the most significant findings are summarized. Zontelli Brothers ore processed at a Cuyuna plant shows the lowest plant cost ($28.328/ton), as well as the

---

[2] Because of excessive freight costs.

[3] The freight rates are a result of conferences with Mr. Bowman Gravelle and Mr. Warren Baldwin of the rate offices of the Great Northern Railroad Company and Northern Pacific Railway Company, respectively, and Mr. R. F. Day, Assistant General Freight Agent, Traffic, Mines and Animals, Soo Line Railroad Company, Room 1632, Soo Line Building, Minneapolis, Minnesota, and Mr. J. F. Fallon, Great Northern Railroad Company, Freight Traffic Manager, Traffic Department, 175 East 4th Street, St. Paul, Minnesota. As to the rate for shipment of Luppen, Butler Brothers vs. Great Northern Railroad Company, et al, 276 I.C.C. 679 (January 9, 1950) seems to decide conclusively that Fe content, density, and ease of handling are not elements which would necessarily justify or demand a concession in freight rate as opposed to direct shipping ore. Consequently, the present iron ore freight rates from all points on the range to Duluth would apply to Luppen and no concessions could be expected.

lowest total cost on board ship ($29.798/ton). Oliver ore at Hibbing has the next lowest plant cost ($29.446/ton), and cost delivered on board ship ($30.916/ton).

Details of the raw material costs for the Cuyuna Range and Hibbing sites, which have the most favorable costs, are as follows:

### Cuyuna Range Plant Using Zontelli Ore

| | Unit | Annual Quantity | Unit Cost Material | Unit Cost Transportation | Annual Cost |
|---|---|---|---|---|---|
| Iron Ore | L. Ton | 1,417,650 | $ 2.00 | --- | $2,835,300 |
| Limestone | S. Ton | 156,585 | 2.55 | $1.20 | 587,194 |
| Anthracite Fines | S. Ton | 430,781 | 10.20 | 1.80 | 5,169,372 |
| Bituminous Coal | S. Ton | 108,218 | 10.23 | 1.80 | 1,301,862 |
| Total Raw Material Cost for 693,690 S. T. Luppen | | | | | $9,893,728 |
| Cost per ton of Luppen | | | $14.262 | | |
| Drying cost per ton | | | .088 | | |
| Total cost (Dry basis) | | | $14.350 | | |

### Hibbing Plant Using Northern Pacific Ore

| | Unit | Annual Quantity | Unit Cost Material | Unit Cost Transportation | Annual Cost |
|---|---|---|---|---|---|
| Iron Ore | L. Ton | 1,443,000 | $ 3.80 | $0.50 | $6,204,000 |
| Limestone | S. Ton | 128,700 | 2.55 | 1.69 | 545,688 |
| Anthracite Fines | S. Ton | 443,942 | 10.20 | 1.80 | 5,327,304 |
| Bituminous Coal | S. Ton | 120,732 | 10.23 | 1.80 | 1,452,406 |
| Total Raw Material Cost for 685,096 S. T. Luppen | | | | | $13,530,298 |
| Cost per ton of Luppen | | | $19.749 | | |
| Drying Cost per ton | | | .103 | | |
| Total cost (Dry basis) | | | $19.852 | | |

### Hibbing Plant Using Oliver Paint Rock Ore

| | Unit | Annual Quantity | Unit Cost Material | Unit Cost Transportation | Annual Cost |
|---|---|---|---|---|---|
| Iron Ore | L. Ton | 1,531,023 | $ 1.00 | $0.50 | $2,296,535 |
| Limestone | S. Ton | 128,700 | 2.55 | 1.69 | 545,688 |
| Anthracite Fines | S. Ton | 443,792 | 10.20 | 1.80 | 5,325,504 |
| Bituminous Coal | S. Ton | 120,732 | 10.23 | 1.80 | 1,452,406 |
| Total Raw Material Cost for 663,365 S. T. Luppen | | | | | $9,620,133 |
| Cost per ton of Luppen | | | $14.502 | | |
| Drying cost | | | .506 | | |
| Total cost (Dry basis) | | | $15.008 | | |

Differences in raw material costs of similar ore sources reflect trans-

portation of ore from range to various plant sites.

It is interesting to note that costs, other than raw material, do not vary using the same ore, but do vary ore to ore. For example, direct labor costs of Northern Pacific ore at Lake Head and Hibbing are the same ($3.641/ton), while direct labor for Oliver ore processed at the same location is $3.760/ton. This variation of costs, such as direct labor, operating costs, etc., with ore is, of course, related to the concentration of iron in the ore. The highest iron concentration ore (Zontelli Brothers) requires less process time per ton produced and thus results in lower costs per ton for labor, and the like.

Details follow for processing Zontelli Brothers ore at Lake Head and the Cuyuna Range.

| | | |
|---|---|---|
| *Labor—Direct* | | |
| $2,011,566 per year | $2.900 per ton | |
| 693,690 annual tonnage produced | | |
| Fringe Benefits 24 per cent | 0.696 per ton | |
| Total Direct Labor Cost per ton | | $3.596 |
| *Operating Cost* | | |
| Electricity 92 Kwh per ton @ .011 per Kwh | $1.012 | |
| Kiln Relining | | |
| $822,649 per year | $1.186 | |
| 693.690 tons per year | | |
| Water 365 Mg/yr. @ $.05/1000 gal. | $0.026 | |
| Repair and Maintenance | | |
| $1,516,363 annual cost | $2.186 | |
| 693.690 tons per year | | |
| Plant Heating | | |
| $60,355 annual cost | $0.087 | |
| 693,690 tons per year | | |
| Total Operating Cost | | $4.497 |
| *Depreciation—20 years* | | |
| $1,895,445 annual cost | | $2.732 |
| 693,690 tons per year | | |
| *Indirect Cost* | | |
| Administrative and Sales Expense | $0.600 per ton | |
| Plant Administration | $193.368 per year | |
| $193,368 annual cost | $0.279 per ton | |
| 693,690 tons per year | | |
| Royalties—Fried. Krupp | $0.360 per ton | |
| Insurance and Sales Tax | 0.400 per ton | |
| Interest | 1.514 per ton | |
| Total Indirect Cost per ton Luppen | | $3.153 |

Inasmuch as these costs are similar for Northern Pacific and Oliver Iron Mining ores, the detail is not shown, but the information is available in the report on file at the Area Redevelopment Administration.

The costs for the three ores analyzed in this study are based in two cases on figures made available from the sources concerned, and in the other case, on discussions with the mining company. If a common min-

ing cost and a uniform grade of ore were available, the average cost per ton of product would be approximately the same in all three locations. Thus, if new ore sources become available, perhaps from state reserves, amenable to the Krupp Renn process, the higher the iron content the lower will be the related costs per ton.

### Evaluation of the Market

The market for Luppen consists of four principal applications:

- Blast Furnaces
- Hot Blast Cupola
- Electric Arc Furnaces
- Oxygen Furnaces

Estimates of market size and value of Luppen are summarized below:

| *Application* | *Market Potential* (Thousands of short tons) | *Value of Luppen* (f.o.b. Lake Head) |
|---|---|---|
| • Blast Furnace | 6,000 | $36.69/short ton |
| • Hot Blast Cupola | N.A.* | 51.00/short ton |
| • Electric Arc Furnaces | 970 | 41.97/short ton |
| • Oxygen Furnaces | 1,000 | 49.32/short ton |

* Not available.

Evaluation of the economic feasibility and return on equity are based on a $35/net ton price on board ship (Lake Head) and $40/net ton price on board ship (Lake Head). A six-kiln plant using Zontelli ore at Cuyuna would have a plant capacity of 693,690 net tons/year. Thus a 694/7,970 or 8.7 per cent penetration of the available market would be required to operate at plant capacity.

Because of the higher value of Luppen in electric arc furnaces and oxygen furnaces as compared with blast furnaces, initial marketing efforts should be devoted to trying to sell plant capacity to the electric arc furnace and oxygen furnace users. This will be more difficult than attempting to sell the market as a whole since it will require a 694/1,970 or 35 per cent penetration to sell plant capacity. However, the ability to obtain the $40/ton price on board ship in Lake Head increases the attractiveness of the project several fold. The enhanced profit from an increase in price from $35 per ton to $40 per ton price is apparent in the financial summary which follows.

The current growth in oxygen furnace capacity should increase the possibility of sale of Luppen—at the $40/ton price for this application. The *Steel* magazine in its September 30, 1963 issue on page 28 details the steel industry's plans for expansion of oxygen furnaces. If these plans are accomplished, oxygen furnace capacity will expand from the current 11,040,000 net annual tons to almost twice that figure—21,400,000 tons by 1965. Luppen's advantages in this application make the growth of oxygen furnace capacity a very positive and significant development.

In addition, there are indications that the use of the hot blast cupola process will also expand in future years.

## Financial Summary

The Krupp Renn process appears to be financially attractive, providing a return on equity of 17.3 to 34.0 per cent processing Zontelli ore at Cuyuna with a plant operating at 100 per cent capacity. However, it is also clear that the degree of financial attractiveness is heavily influenced by two factors:

- Price received on board ship.
- Percent utilization of capacity.

The net income of each plant site and ore combination is shown in Table 2. Table 2 details sales, manufacturing cost, freight to ship, gross profit, administrative expenses, income before tax, federal income tax, and net income for each plant site and ore combination for a $35/ton and $40/ton price on board ship.

Zontelli Brothers ore processed at Cuyuna remains the best combination, producing a net income of $1,738,000 at a $35/ton price ranging to a $3,403,000 net income at a $40/ton price. Oliver iron ore processed at Hibbing is second best, with a net income ranging from $1,285,000 to $2,876,000 on a similar basis. These calculations are all based on operating at 100 per cent capacity.

Chart 1 shows the effect of various operating rates on gross profit for the best alternatives—Zontelli ore processed at Cuyuna. The breakeven point for the $35/ton price is 58 per cent whereas it drops to 43 per cent for the $40/ton price.

Because the two major variables: Price, and per cent of plant utilization are so important, the variances in each are set out in the following tabulation—based on the best combination—Zontelli ore processed at Cuyuna:

- Price variance from $35/ton to $40/ton results in a gross profit variance of $3,469,000 or $693,000 per $1 price charge.

- Operating rate variances of 1 per cent result in a reduction in gross profit of $75,000 per cent for the $35/ton price, and a reduction of $110,000 per cent for the $40/ton price.

The significance of these variances is obvious. Major efforts must be placed on maintaining the highest operating rate and highest price. Of course, in practice, operating rate and price will have to be balanced to arrive at the optimum profit.

For example, faced with the alternative of selling plant capacity at a $35/ton price or somewhat less than capacity at a $40/ton price, Chart 1 indicates that a marketing strategy directed towards obtaining the higher price is more profitable as long as the plant could be operated in excess of 73 per cent of capacity. This is so because at 73 per cent of capacity at a $40/ton price the plant produces the same income before tax as 100 per cent of capacity operation at the $35/ton price. Thus Chart 1 becomes a valuable economic tool for evaluating various alternatives.

Table 3 summarizes the cash flow which would be produced from each ore and plant combination. Obviously the lowest cost, higher profit combination—(Zontelli ore processed at Cuyuna)—still remains the most attractive combination. Three factors: depreciation, provision

for interest, and loan payment, remain constant in each combination. Zontelli ore processed at Cuyuna, with the plant operating at 100 per cent of capacity, would result in a cash return on the $10,000,000 equity investment of between 17.3 to 34.0 per cent. At 90 per cent of capacity the process still remains attractive providing a cash return on investment of from 13.4 to 24.6 per cent.

As commented on earlier, the return from this investment would improve if the plant were added to an existing facility.

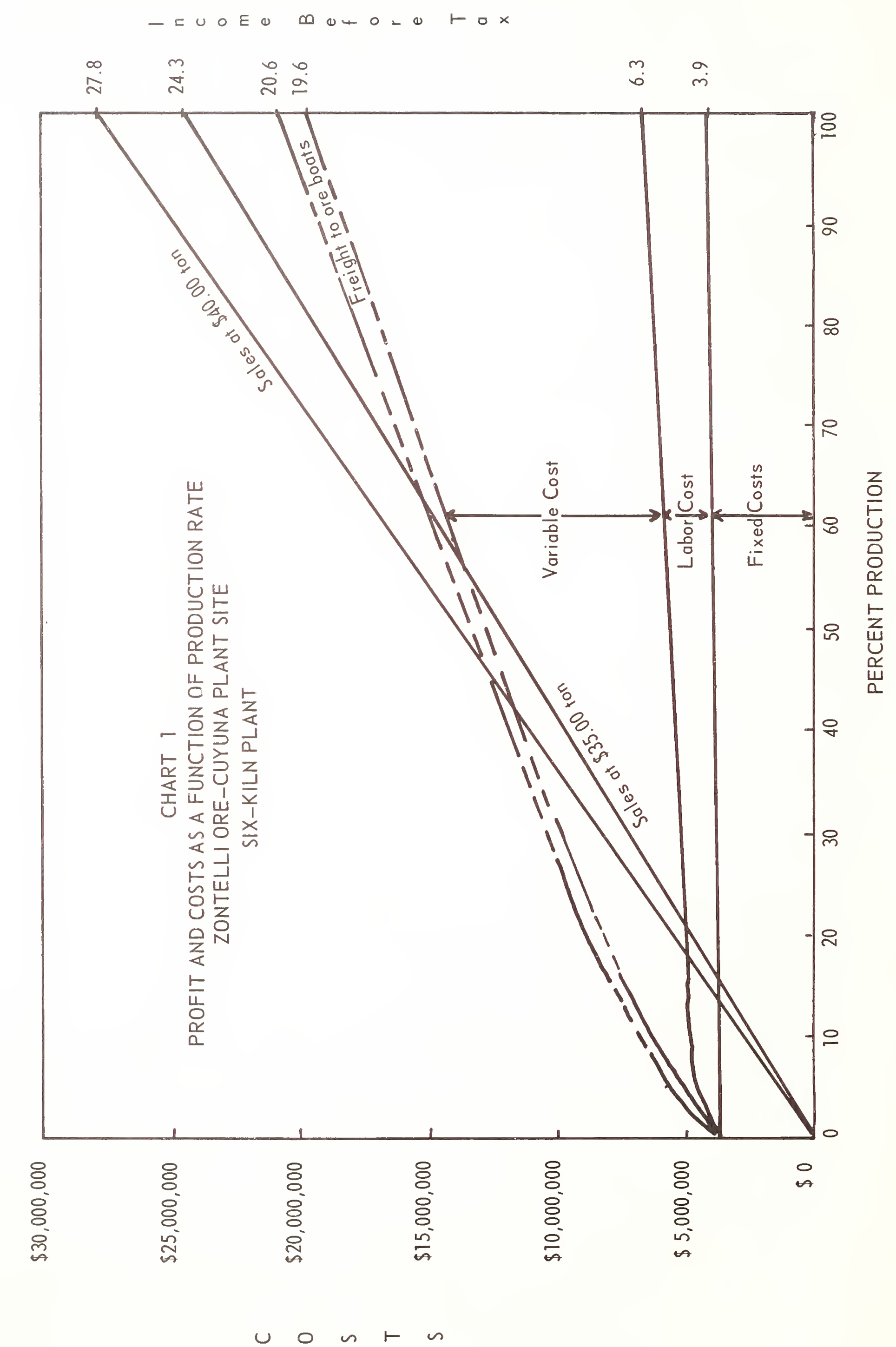


CHART 1
PROFIT AND COSTS AS A FUNCTION OF PRODUCTION RATE
ZONTELLI ORE–CUYUNA PLANT SITE
SIX–KILN PLANT
COSTS
$30,000,000
$25,000,000
$20,000,000
$15,000,000
$10,000,000
$ 5,000,000
$ 0
PERCENT PRODUCTION
0
10
20
30
40
50
60
70
80
90
100
Income Before Tax
27.8
24.3
20.6
19.6
6.3
3.9
Sales at $40.00 ton
Sales at $35.00 ton
Freight to ore boats
Variable Cost
Labor Cost
Fixed Costs

**TABLE 1**

**COST SUMMARY OF SIX KILN PLANT OPERATION BY ORE SOURCE, BY LOCATION IN $/TON**

| | | Possible Plant Sites | | |
|---|---|---|---|---|
| *Ore Source* | *Principal Costs* | *Lake Head* | *Hibbing* | *Cuyuna* |
| Zontelli Brothers, Semi-Taconite Cuyuna Range, Crosby-Ironton, Minnesota | Raw Material | $16.365 | | $14.350 |
| | Labor—Direct | 3.596 | | 3.596 |
| | Operating Costs | 4.497 | | 4.497 |
| | Depreciation | 2.732 | | 2.732 |
| | Indirect Costs | 3.153 | | 3.153 |
| | Total Costs at Plant | $30.343 | | $28.328 |
| | Freight to Ship | 1.20 | | 1.47 |
| | Total Costs on Ship | $31.543 | | $29.798 |
| Northern Pacific, Semi-Taconite, Central Mesabi Range, Bovey | Raw Material | $21.191 | $19.852 | |
| | Labor—Direct | 3.641 | 3.641 | |
| | Operating Costs | 4.540 | 4.540 | |
| | Depreciation | 2.767 | 2.767 | |
| | Indirect Costs | 3.156 | 3.156 | |
| | Total Costs at Plant | $35.295 | $33.956 | |
| | Freight to Ship | 1.20 | 1.47 | |
| | Total Costs on Ship | $36.395 | $35.426 | |
| Oliver Iron Mining Division Paint Rock—Hibbing Area | Raw Material | $16.059 | $15.008 | |
| | Labor—Direct | 3.760 | 3.760 | |
| | Operating Costs | 4.655 | 4.655 | |
| | Depreciation | 2.857 | 2.857 | |
| | Indirect Costs | 3.166 | 3.166 | |
| | Total Costs at Plant | $30.497 | $29.446 | |
| | Freight to Ship | 1.20 | 1.47 | |
| | Total Costs on Ship | $31.697 | $30.916 | |

TABLE 2

SUMMARY—PROFORMA STATEMENT OF ANNUAL INCOME OF SIX-KILN PLANT BY ORE SOURCE, BY LOCATION

| | | *Possible Plant Sites* | | | | | |
|---|---|---|---|---|---|---|---|
| | | *Lake Head* | | *Hibbing* | | *Cuyuna* | |
| *Ore Source* | *Item* | *$35/Ton** *(Thousand)* | *$40/Ton*** *(Thousand)* | *$35/Ton* *(Thousand)* | *$40/Ton* *(Thousand)* | *$35/Ton* *(Thousand)* | *$40/Ton* *(Thousand)* |
| Zontelli Brothers, | Net Sales | $24,279 | $27,748 | | | $24,279 | $27,748 |
| Semi-Taconite | Mfg. Cost | 18,862 | 18,862 | | | 17,464 | 17,464 |
| Cuyuna Range, | Freight to Ship | 832 | 832 | | | 1,020 | 1,020 |
| Crosby-Ironton, | Gross Profit | 4,585 | 8,054 | | | 5,795 | 9,264 |
| Minnesota | Admin. Expenses | 2,174 | 2,174 | | | 2,174 | 2,174 |
| | Income Before Tax | 2,411 | 5,880 | | | 3,621 | 7,090 |
| | Federal Income Tax | 1,254 | 3,058 | | | 1,883 | 3,687 |
| | Net Income | $ 1,157*** | $ 2,822 | | | $ 1,738 | $ 3,403 |
| Northern Pacific, | Net Sales | $23,978 | $27,404 | $23,978 | $27,404 | | |
| Semi-Taconite, | Mfg. Cost | 22,018 | 22,018 | 21,101 | 21,101 | | |
| Central Mesabi | Freight to Ship | 822 | 822 | 1,007 | 1,007 | | |
| Range, Bovey | Gross Profit | 1,138 | 4,564 | 1,870 | 5,296 | | |
| Minnesota | Admin. Expenses | 2,162 | 2,162 | 2,162 | 2,162 | | |
| | Income Before Tax | ( 1,024) | 2,401 | ( 292) | 3,134 | | |
| | Federal Income Tax | —0— | 1,249 | —0— | 1,629 | | |
| | Net Income | ($ 1,024) | $ 1,153 | ($ 292) | $ 1,504 | | |
| Oliver Iron | Net Sales | $23,218 | $26,536 | $23,218 | $26,536 | | |
| Mining Division | Mfg. Cost | 18,131 | 18,131 | 17,433 | 17,433 | | |
| Paint Rock— | Freight to Ship | 796 | 796 | 975 | 975 | | |
| Hibbing Area | Gross Profit | 4,291 | 7,607 | 4,810 | 8,126 | | |
| | Admin. Expenses | 2,133 | 2,133 | 2,133 | 2,133 | | |
| | Income Before Tax | 2,158 | 5,475 | 2,677 | 5,993 | | |
| | Federal Income Tax | 1,122 | 2,847 | 1,392 | 3,116 | | |
| | Net Income | $ 1,036 | $ 2,628 | $ 1,285 | $ 2,876 | | |

* Represents minimum price.
** Represents maximum price.
*** Statistics are rounded here in summary, so do not necessarily add exactly.

## TABLE 3
## SUMMARY—CASH FLOW OF SIX KILN PLANT OPERATION BY ORE SOURCE, BY LOCATION

| | | Possible Plant Sites | | | | | |
|---|---|---|---|---|---|---|---|
| | | Lake Head | | Hibbing | | Cuyuna | |
| Ore Source | Item | $35/Ton* (Thousand) | $40/Ton* (Thousand) | $35/Ton (Thousand) | $40/Ton (Thousand) | $35/Ton (Thousand) | $40/Ton (Thousand) |
| Zontelli Brothers, | Net Income | $ 1,157 | $2,822 | | | $1,738 | $3,403 |
| Semi-Taconite | Add: Depreciation | 1,895 | 1,895 | | | 1,895 | 1,895 |
| Cuyuna Range, | Provision for Interest | 1,037 | 1,037 | | | 1,037 | 1,037 |
| Crosby-Ironton, | | | | | | | |
| Minnesota | Sub-Total | $ 4,089 | $5,754 | | | $4,670 | $6,335 |
| | Deduct: Loan Payment | 2,938 | 2,938 | | | 2,938 | 2,938 |
| | Excess Cash Available | $ 1,151 | $2,816 | | | $1,732 | $3,397 |
| | Cash Return on Invest.** | 11.5% | 28.2% | | | 17.3% | 34.0% |
| Northern Pacific, | Net Income | $(1,024) | $1,153 | $ (292) | $1,504 | | |
| Semi-Taconite | Add: Depreciation | 1,895 | 1,895 | 1,895 | 1,895 | | |
| Central Mesabi | Provision for Interest | 1,037 | 1,037 | 1,037 | 1,037 | | |
| Range, Bovey | | | | | | | |
| Minnesota | Sub-Total | $ 1,908 | $4,085 | $2,640 | $4,437 | | |
| | Deduct: Loan Payment | 2,938 | 2,938 | 2,938 | 2,938 | | |
| | Excess Cash Available | $(1,030) | $1,148 | $ (298) | $1,499 | | |
| | Cash Return on Investment | —0— | 11.5% | —0— | 15.0% | | |
| Oliver Iron | Net Income | $ 1,036 | $2,628 | $1,285 | $2,876 | | |
| Mining Division | Add: Depreciation | 1,895 | 1,895 | 1,895 | 1,895 | | |
| Paint Rock— | Provision for Interest | 1,037 | 1,037 | 1,037 | 1,037 | | |
| Hibbing Area | | | | | | | |
| | Sub-Total | $ 3,968 | $5,560 | $4,217 | $5,809 | | |
| | Deduct: Loan Payment | 2,938 | 2,938 | 2,938 | 2,938 | | |
| | Excess Cash Available | $ 1,030 | $2,623 | $1,279 | $2,872 | | |
| | Cash Return on Investment | 10.3% | 26.2% | 12.8% | 28.7% | | |

* Price on board ship.
** Based on $10,000,000 Equity Investment.

☆ U.S. GOVERNMENT PRINTING OFFICE : 1964 O - 735-141

DEPARTMENT OF COMMERCE
UNITED STATES OF AMERICA